Abstract

Objectives: The objectives of this study were to explore the relationship between acute (1 week) and chronic (4-week average) bowling workloads and injury risk in National Development Programme fast bowlers, and to investigate individual differences in the relationship between acute:chronic workloads and injury.

Design: Prospective cohort study

Methods: Bowling workloads and injury data were collected prospectively for 29 male fast bowlers (age range 15-18) on a National Programme over two years. Workload variables were calculated and the likelihood of injury and individual effects were explored using a generalised linear mixed effects model and magnitude-based inferences.

Results: Acute:chronic workloads of 109-142% (relative risk [RR]: 1.46, 90% CI: 0.93 to 2.29; likely harmful), and ≥ 142% (RR: 1.66, 90% CI: 1.06 to 2.59, likely harmful) were associated with a substantial increase in injury risk compared with the reference quartile (< 87%). A high chronic workload (> 83 balls) substantially attenuated the influence of a high (> 108%) acute:chronic workload ratio on injury risk (RR: 0.35, 90% CI: 0.17 to 0.74). Significant individual differences in the acute:chronic workload-injury relationship were evident.

Conclusion: The present study provides further evidence of the association between 'spikes' in workload and injury risk, but also demonstrates that this relationship is individual-specific and dependent on the level of chronic workload. Support teams for fast bowlers should monitor bowling workloads to avoid rapid fluctuations but should also base decisions on individualised data.

Key Words: Cricket Injures, Cricket bowling, sports, workload, individuality, male

Introduction

Cricket is a popular sport within the UK and worldwide. As is the case in most sports, optimising player availability is beneficial to team performance.[1] Previous research has consistently highlighted that fast bowlers are at increased risk of injury in comparison with other team members.[2,3,4] Of particular concern are gradual onset injuries, such as lumbar stress fractures, which can be season-ending. However sudden onset injuries, such as thigh and hamstring strains have also been found to be a significant issue in male cricketers.[5] Orchard et al. [6] reported an injury prevalence rate of approximately 16% over a 10 year period in elite male fast bowlers.[6] Much of the injury research in cricket focuses on adult populations, however adolescent fast bowlers may be at increased risk of injury due to their developing musculoskeletal system.[7]

Bowling workload is of particular interest as this a potentially modifiable risk factor, particularly in younger fast bowlers, where long term development is a primary focus. Whilst there have been numerous studies investigating the relationship between bowling workload and injury in senior male cricketers [8,9,10,11] there have been comparatively few in adolescent cricketers. Dennis et al.[8] have demonstrated that a dual threshold may exist beyond which the risk of injury increases. They found that bowling at a frequency of every 2-5 days, bowling between 123-188 deliveries per week and bowling 2-3 sessions per week was protective of injury in adult first class state Australian fast bowlers. In adolescent bowlers, the same authors found a trend towards high bowling workload and injury risk.[12] Specifically, they found bowling more frequently than every 3.5 days increased the risk of injury, highlighting the importance of non-bowling days. Despite these findings, an English study [13] found no correlation between workload and injury in a similar age group population, which may be due to only including match workloads. Published data involving adolescent cricketers therefore remains limited to two studies with conflicting results.[12,13]

There is emerging evidence from rugby league,[14] Australian football,[15] cricket,[9] and elite adolescent footballers,[16] that acute:chronic workload ratio may be associated with injury risk. Acute:chronic workload ratio refers to the absolute (acute) one week workload relative to the average four week (chronic) workload. This enables an individual's acute workload to be viewed in relation to the work they have done previously, therefore giving an idea of preparedness.[16] However, no studies to date have considered the repeated observations made across fast bowlers in these analyses, which may bias the results.[17] In addition, there are likely to be large individual differences in the nature of the workload-injury relationship, and so methods to account for and explore these differences are warranted.

The current study planned to contribute new evidence concerning cricket bowling workloads and injury by examining an adolescent population and further examining the notion that acute:chronic workload ratio can influence injury risk. The specific aims for this study were therefore to explore the relationship between acute (1 week) and chronic (4-week average) bowling workloads and injury risk in National Development Programme fast bowlers, and to investigate individual differences in the relationship between acute:chronic workloads and injury.

Methods

Participants for this study were 23 male fast bowlers (mean age 16.7 +/- 1.2 years, range 15 -18 yrs) selected onto the England and Wales Cricket Board Development Programme between October 2012 and October 2014. Players were selected onto this programme on the basis of having the potential to play senior international cricket. A fast bowler was defined as 'a bowler for whom the wicketkeeper would normally stand back from the stumps.' Data was collected continually for two years from October 2012 to October 2014. As seven of these fast bowlers were on the programme for more than one year, this produced 30 full year blocks of data for analysis. Ethical approval was obtained from the University of Bath and the England and Wales Cricket Board gave permission for the study.

Written participant consent and parental/guardian consent (for participants under the age of 18) was also obtained.

Workload and injury data were collected on a weekly basis by the physiotherapists working on the programme. Both training and competition bowling workloads were collected. Other non-bowling workloads, such as batting and strength and conditioning were not included. Workloads were self-reported weekly by fast bowlers to the team physiotherapist and included the number of overs bowled and on what days these were bowled. Bowling drills, balls bowled in warm ups and intensity of bowling were not included. A variety of methods were used to collect workload information including email, text and telephone in order to improve compliance. Where further information was required or data was not received this was followed up by telephone within 24 hours. Data was categorised into weekly blocks running from Sunday to Saturday.

A validation study was also carried out to ascertain whether workload reporting by fast bowlers was sufficiently representative of true workload. Whilst on an overseas tour, self-reported match and training bowling workloads were collected for five fast bowlers over a 17 day period by the team physiotherapist. Actual workloads were also collected by using match scorecards and direct observation. Differences between reported and actual workloads were assessed using mean difference. Analysis of the difference between overall reported bowling workloads and actual workloads showed good validity. There was a mean difference of 0.21 balls between actual and reported workloads for the five bowlers included in the analysis.

Injury data was collected alongside weekly workload data using self-report. an injury was defined as ‘all non-contact injuries considered to be fast bowling related that resulted in a loss of either match or training time’. This definition was chosen in order to capture both gradual and sudden onset injuries. All reported injuries were followed up and assessed by the fast bowler’s county, club or national physiotherapist, depending on location at the time of the injury. Location of injury (body part) and a diagnosis was recorded by the relevant physiotherapist using the Orchard Sports Injury Classification System, Version 10.[18] All physiotherapy and medical staff working with the fast bowlers recorded any medical information on the global electronic notes system, used routinely for all medical documentation. Where further information was required, notes were retrieved from this system by the author.

All estimations during data analysis were made using the lme4 package with R (version 3.2.4, R Foundation for Statistical Computing, Vienna, Austria).[19] Total number of balls bowled on each day for each fast bowler was summarised into weekly blocks. Acute (one week) and chronic (four week rolling average) workloads were then calculated. The chronic workload included the most recent week, in the same manner as previous work.[9] Weeks where no balls were bowled, for example during travel or a rest period, were included in order to examine the effect of periods of low workload on subsequent injury.

The acute:chronic workload ratio was calculated by dividing acute workload by chronic workload.[9] A generalized linear mixed-effects model (GLMM) was used to model the association between workloads and injury risk in the subsequent 4-week period.[10] This mixed effects model was selected for its ability to account for repeated measurements and to explore individual responses between workloads and injury risk. Acute workloads, chronic workloads, and acute:chronic workload ratios were independently modelled as fixed effects predictor variables. Random effects were bowlers identity (differences between bowlers' mean injury risk) and bowler × season (variability within bowlers between seasons) and the residual. To assess the interaction between chronic workloads and the acute:chronic workload ratio, both variables were dichotomised by the median score (83 balls and 108%, respectively) and included as interaction terms in the model.

If assessment of a quadratic trend between the workload measure and injury risk was significant ($P \leq 0.05$), the measure was split into quartiles for analysis, with the lowest load range being the reference group. Otherwise, linear effects for continuous predictor variables were evaluated as the change in injury risk (relative risk [RR] associated with a two standard deviation increase in the workload measure.[20] The odds ratios obtained from the GLMM model were therefore converted to relative risks in order to interpret their magnitude.[21,22] A likelihood ratio test [23] was used to determine whether model fit was significantly improved when using GLMM in comparison with a logistic regression model (which does not account for repeated measurements or individual variations in responses).

Magnitude-based inferences were used to provide an interpretation of the real-world relevance of the outcomes.[24] The smallest worthwhile increase in risk for time-loss injuries was a relative risk of 1.11, and the smallest worthwhile decrease in risk was 0.90.[25] An effect was deemed unclear if the chance that the true value was beneficial was >25%, with odds of benefit relative to odds of harm (odds ratio) of <66. Otherwise, the effect was deemed clear, and was qualified with a probabilistic term using the following scale : <0.5%, most unlikely; 0.5-5%, very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99.5%, very likely; >99.5%, most likely.[26]

Results

There were 32 injuries during the study period, all to the trunk and lower limb (Table 1). In the 2012/2013 and 2013/2014 years, 60% and 67% of fast bowlers sustained an injury related to bowling, with 31% of fast bowlers sustaining more than one injury over the two years.

With regards to acute and chronic workloads, a two standard deviation increase, moving from a ‘typically low’ to a ‘typically high’ level, in acute workload (130 balls) was associated with a substantial increase in injury risk in the subsequent four week period (relative risk: 4.16, 90% CI: 2.55 to 6.78; most likely harmful) (see Table 2). Similarly, a two standard deviation increase in chronic workload (96 balls) was associated with a substantial increase in injury risk in the subsequent four week period (relative risk: 5.19, 90% CI: 3.05 to 8.82; most likely harmful).

With regards to acute:chronic workload ratio, a significant non-linear effect was evident for the acute:chronic workload ratio, acute:chronic workloads of 109-142% (relative risk: 1.46, 90% CI: 0.93 to 2.29; likely harmful), and ≥ 142% (relative risk: 1.66, 90% CI: 1.06 to 2.59; likely harmful) were associated with a substantial increase in injury risk compared with the reference quartile (< 87%) (Table 1). The effect for an acute:chronic workload ratio in the range of 87 – 109% (relative risk: 0.92, 90% CI: 0.56 to 1.52) was unclear when compared to the reference quartile. A significant interaction effect was evident between chronic workloads and the acute:chronic workload ratio, such that a high chronic workload (> 83 balls) substantially attenuated the influence of a high (> 108%) acute:chronic workload ratio on injury risk in the subsequent four week period (relative risk: 0.35, 90% CI 0.17 to 0.74) (Figure 1).

The likelihood ratio test comparing the GLMM and logistic regression model fits was significant, and indicated a substantial improvement in model fit when random effects were included in the model (logistic regression model log likelihood = -364.4, GLMM log likelihood = -348.9, $P<0.001$). Therefore, individual differences in workload-injury relationships were evident. Figure 2 displays the relationship between acute:chronic workload ratios and injury risk in the subsequent four week period for each individual in the analysis, as estimated via the GLMM.

Discussion

This is the first study that has investigated the relationship between acute:chronic bowling workload ratio and injury risk in fast bowlers on an elite development programme. It clearly demonstrated a non-linear relationship between acute:chronic workload and injury risk in the subsequent four weeks, however this relationship was individual-specific and could be mitigated by having a greater chronic workload. The study also showed that an increase in acute workload and chronic workload of more than two standard deviations (22 and 16 overs respectively) resulted in a 4-5 fold increase in injury risk in the subsequent 4 weeks.

This study supports the findings of previous studies in senior fast bowlers that found an increased risk of injury after workload spikes that persisted for up to four weeks.[9,10,11] The finding that a high chronic workload reduced the impact of workload spikes on injury risk, was similar to Hulin et al.[9] who suggested that a high chronic workload was associated with a reduced risk of injury in senior bowlers. This may be because it is much harder to achieve a spike in workload if you already have a high chronic workload. In contrast to Hulin el al.[9] however, the current study found that higher chronic workloads themselves increased the risk of injury. This may be due to the differences in age group in each study, as it has been demonstrated the type of tissue injured varies between different age groups of fast bowlers and that different workload patterns resulted in different Injuries.[27,28] It has been found that younger bowlers were more likely to sustain bone stress injuries whereas older bowlers were more likely to sustain tendon injuries[27] and other studies have found that high medium term workload increased risk of bone stress injuries but reduced the risk of tendon injuries.[28]

The individual variations in risk could be due to other moderating factors not examined in this study. For example, intrinsic risk factors such as bowling technique [29,30] and physiological characteristic such as strength, range of movement and cardiovascular fitness.[29] However only a few high quality studies exist in this area, most are retrospective in nature and very few monitored bowling workload.[30] Bayne et al.[31] found a number of biomechanical and musculoskeletal factors related to low back pain in a group of adolescent fast bowlers, yet they found no relationship between bowling workloads and injury risk. However they did not include acute:chronic workload as part of their analysis. Future studies should examine the impact of intrinsic risk factors and the individual specific injury risk associated with acute:chronic workload.

The findings of the current study support the use of workload monitoring for fast bowlers to reduce injury risk and have practical implications for the management of fast bowlers during pre-season, in-season and return to play from injury. The number of overs a bowler can bowl will vary depending upon the game. Bowlers are restricted to a maximum of 4 overs in T20 and 10 in a one day matches. However in multi-day cricket there are no restrictions on the number of overs a bowler can deliver and they are regularly required to bowl 30 to 40 overs, and could possibly bowl more than 50 overs in first class cricket match (4 day game). This allows a practitioner to predict the maximum amount of overs a bowler is likely to bowl and therefore what acute:chronic workload ratio, as well as the acute and chronic workload they need to minimise the risk of injury.

If the competition schedule is known for a forthcoming season the practitioner can plan pre-season training workloads to ensure fast bowlers are prepared for competition workload. For example, if the first game of the season is a 4 day match each fast bowler needs to be prepared to bowl at least 40 overs during that match. To minimise their risk of injury based on the findings of this study they need a chronic workload of at least 29 overs to have an acute:chronic ratio under 142% or 37 overs to be under 109% and their acute workload for the previous week needs to be at least 19 overs. By using this approach the practitioner can then work backwards to plan the bowling workload for the entire pre-season.

During the season a fast bowlers training overs may be adjusted on the basis of workload monitoring to minimise injury risk. If a bowler had bowled more overs than expected during a match their subsequent training overs could be reduced to minimise any workload spike. However if a bowler had bowled less overs than expected during a match, they may need to increase their training overs to maintain sufficient chronic workload to minimise injury risk. Orchard et al.[5] reported that the advent of T20 cricket competitions such as the Big Bash and the IPL, has led to fast bowlers experiencing rapid increases in bowling workload as the game format changes to multi-day cricket. Therefore bowlers may need to bowl extra overs in training during these competitions to ensure their chronic load is sufficient to reduce the risk of injury when resuming multi-day cricket. For example if they are playing three T20 games a week, which means they could bowl only 12 overs maximum in competition, a bowler would need to bowl another 17 overs in training to have a chronic load of 29 overs or another 25 overs to have a chronic workload of 37 overs.

It is possible that match overs could be planned for individual bowlers based on their bowling workloads and bowlers could potentially be rested from specific matches. To do so would require the significant buy in from the captain, coach and player [32] and any planned match workload could be affected by injuries to other players, playing tactics and how well the opposition is batting.

Past history of injury is a significant predictor of subsequent injury and many reasons have been proposed for why this occurs.[33] More recently it has been proposed that this may be because athletes have done insufficient training during recovery from injury to be adequately prepared for the demands of the game.[34] By monitoring bowling workloads during rehabilitation from injury, a practitioner can progress the players bowling workload gradually to reduce the risk of re-injury. It also allows them to identify if a player is at risk re-injury upon return to competition which can inform decisions on return to play.

Recently more sophisticated methods which use microtechnology incorporating global positioning system (GPS) technology and inertial measurement units have been developed and validated to record bowling workload.[35] This technology is thought to be more reliable than self-reporting methods and also provides information regarding the intensity of each ball bowled. However, this is costly and requires specific hardware and software which may affect its ease of use.[36] Human factors can also affect its use; the units need to be present for all match and training sessions and sufficiently charged to ensure all workloads are captured. The accuracy of the units depends upon requires tight fitting clothing [37] which some players do not want to wear as they may find it uncomfortable. The self-report method for bowling workload was used in this study as it is a reliable and valid method of monitoring bowling workloads and it is cost effective and easy to implement. This is important especially for practitioners working in adolescent sport who do not have the financial and human resources associated with professional senior teams.

The study focused on the relationship between acute:chronic bowling workload ratio and injuries in elite adolescent fast bowlers. At present it is unknown if these findings apply to other groups of fast bowlers, such as female cricketers, as there are no previous workload studies in this population. Recent developments such as professional cricket leagues are likely to increase the drive for evidence based injury prevention strategies for the women's game. Further research should investigate other external and internal load measures involved in cricket, including time spent batting or fielding, or other activities such as strength and conditioning training, and their relationship to injuries sustained by all skill and age groups. Furthermore, it would be useful to consider using daily rolling acute and chronic workload calculations, as opposed to using weekly blocks, in order to improve the quality of the analysis.

Conclusion

This study demonstrated that simple field based measures can be used effectively to monitor bowling workload and determine injury risk. A non-linear relationship between acute:chronic bowling workload ratio and injury in the subsequent four weeks was demonstrated, however higher chronic workloads mitigated this risk. Practitioners working in cricket should use this information to plan pre-season bowling workloads to prepare players for the demands of competition. In-season player's workloads should be monitored closely, observing for any increase in acute:chronic workload ratio or significant increases in acute or chronic workload. If this is observed the practitioner should consider changing training or match bowling workloads to reduce their risk of injury. When returning from injury it is important to consider if the player has completed sufficient bowling in training to handle the demands of competition.

Practical Implications

- Acute:chronic workload ratio is linked to injury in adolescent fast bowlers
- There is clear individual variation in response to workload, which is dependent on previous chronic workload
- Self-reported bowling workloads are reliable and linked to injury and this is therefore an effective monitoring tool

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Table 1: Breakdown of time loss injury episodes by specific regions.

Region	% of total time loss injury episodes by global region	% of total time loss injury episodes by specific region	
Lower limb	53%	Ankle	19%(n=6)
		Posterior thigh	9% (n=3)
		Foot	9% (n=3)
		Shin	6% (n=2)
		Anterior thigh	6% (n=2)
		Hip	3% (n=1)
Spinal/trunk	47%	Lower back	38% (n=12)
		Side strain	9% (n=3)

Table 2. Relationships between workload variables and injury risk in the subsequent 4 week period.

Variable	**2 SDs**	**Effect of 2 SD increase** (relative risk with 90% CI)	***P*-Value**	**Inference**	**% likelihood effect is beneficial | trivial | harmful**
Acute workload	130 balls	4.16 (2.58 – 6.72)	0.000001	Most likely harmful	0 | 0 | 100%
Chronic workload	96 balls	5.19 (3.06 – 8.81)	0.0000003	Most likely harmful	0 | 0 | 100%
Acute:chronic workload					
<87% (reference)		1.00			
87 to <109%		0.92 (0.23 – 3.60)	0.92	Unclear	49 | 10 | 41%
109 to <142%		1.46 (0.93 – 2.30)	0.17	Likely harmful	4 | 11 | 85%
≥142%		1.66 (1.07 – 2.59)	0.06	Likely harmful	1 | 5 | 94%

Figure Legends

Figure 1. Interaction effect between chronic workload and acute:chronic workload ratio. * denotes substantial change in injury risk between the low chronic workload and high chronic workload groups.

Figure 2. Individual effects for the relationship between acute:chronic workload ratio and injury risk in the subsequent four week period. Each letter represents an individual player in the analysis. Shaded areas represent 90% confidence intervals.